A Digital EEG Laboratory - Distributed Systems for Data Acquisition and Clinical Support

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Recording electroencephalograms(EEG) and other neurophysiological signals traditionally involves dedicated analog amplifiers and multichannel stripchart pen-recorders. Modern instrumentation is now computer-based, providing analog-to-digital conversion and digital output using graphics CRTs and laser printers for display of waveforms. The emergence of digital systems provides a platform for integration of the various diagnostic instruments in a Clinical Neurophysiology Laboratory.

A typical analog instrument, such as an EEG machine, accomplishes data acquisition, signal processing, display, and archive functions all in a single, standalone unit. Using digital systems, it becomes practical to separate these functions into independent modules; for example, the EEG signal acquisition can be done at the bedside, with display of waveforms at a remote location at a later time. Furthermore, software-based systems can be dynamically reconfigured, so that a single digital system can perform the functions of several different analog instruments. Using standard computer networking, acquisition and waveform display systems can be distributed throughout the laboratory, in the operating rooms, at intensive care unit (ICU) beds, etc. Display systems can be located where most convenient for the physicians to analyze the waveforms, and can view data from any of the acquisition stations using a common user-interface. Waveform displays can be enhanced using computer signal processing and integration of textual annotations from a laboratory information system database. Paper output is drastically reduced, and can be centralized so that only a few printers are necessary for a large laboratory. Archive of digital data can likewise be centralized.

The Cleveland Clinic neurophysiology laboratory consists of 8 beds for 24-hour continuous EEG/video monitoring, 4 polysomnography beds for sleep evaluation, operating room and ICU monitoring, as well as performing more than 10,000 routine diagnostic studies per year. If traditional analog instrumentation were used, more than 50 miles of stripchart would be generated each day, at a cost of nearly $3 million / year for paper alone.

Analog systems have been replaced with a network (ethernet and TCP/IP) of 20 HP9000 series UNIX workstation-based acquisition and display systems for acquisition of neurophysiological waveforms and synchronized patient video recording. Three HP9000/835 UNIX time-sharing minicomputers provide operational and administrative support, including an extensive database management system for scheduling, reporting, archiving, and research queries; the database contains textual information for approximately 35,000 patient studies since 1989. Together, the real-time waveform data acquisition systems collect approximately 15 Mbytes of digitized waveform data per minute, 24 hours per day. These systems are used in assembly-line fashion to coordinate the activities of 10 physicians, 27 EEG technologists, 4 nurses, as well as secretaries and receptionists.

Custom application programs provide immediate access to data on any of the acquisition systems from any other system. Waveforms are reviewed at 5 screens per second (16 channels, 10 seconds), faster than the physician can turn pages using stripchart paper. Interesting segments of data can be identified and annotated, automatically by the computer or by a human reviewer. Advanced signal processing is integrated, including real-time montage reformatting, FFT, spike and seizure detection, cursor measurements, etc. Textual information from the clinical database can be incorporated. Interactive terminal sessions can be initiated with other information systems in the hospital, including the HIS, laboratory system, radiology reporting systems. Additionally, image processing software allows viewing radiological images (MRI, CT, PET) over the network.

0195-4210/94/$5.00